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Two fertile fields for research on the relationships between public policies and innovation are transportation and environmental protection. In both cases numerous policy instruments having different purposes, some of which are unrelated to the rate and direction of technological change, have been brought to bear on a rather diverse collection of related industries, some regulated relatively heavily and others subject to only a few administrative controls.

Unfortunately, relatively few studies of the effect of transportation or environmental policy actions on innovation have been undertaken, and apparently no comprehensive study has ever been made in either area of how policies interact or how their impact differs according to such factors as market concentration or extent of regulation.

ENVIRONMENTAL POLICY

Almost no research has been directed at the relationship between environmental policies and technological change. Two theoretical studies have investigated parts of this relation, and no detailed empirical work has been undertaken. The rest of the literature contains nothing more than obiter dicta and reasonable though fundamentally unproven observations on the performance of various policies in inducing technical change in areas directly related to environmental consequences. The effects of environmental policy on unrelated R&D activities of affected firms appear not to have been considered at all.

This section of this paper summarizes and evaluates the few explicit contributions to this subject. The scattered conjectures are also collected together and evaluated.

Theoretical and empirical work in environmental economics and policy has concentrated almost exclusively on the choice of production technology from a fixed and known set of technological alternatives. If there is anything to the distinction between factor substitution and technological change, this work has little to contribute to our subject. Only those changes in technology characterized by uncertainty and fixed costs, which constitute innovations, are relevant. This definition excludes a large number of articles, especially in engineering journals, whose titles suggest relevance only because technological change is typically defined as a switch from one well-known method to another.

Three relevant topics have recieved some attention. First, there have been some explorations of the differences in impact on technical change among various types of environmental regulation. Second, some attempts have been made to discover the long-run consequences for the direction of technical change of either neglect or regulation of environmental effects. Finally, there have been a few studies of how R&D decisions in specific industries have been affected by environmental policy.

The three ideal types of pollution control policy studied in static models have been private negotiations, effluent charges and standards. Richard Zerbe [1970] has made some commonsense comparisons of these types of pollution control regulations with respect to technical change. His diagrammatic,

partial equilibrium analysis does not provide any definitive answers. His basic conclusion is that emission taxes have a more desirable effect than direct controls on the incentive to invent or adopt a new process which would reduce emissions controls. Subsidies may be superior to direct controls with respect to innovation, but not in all cases. The conclusions are based on the observation that under direct controls the only incentive for adopting an invention comes from its reducing the cost of meeting a fixed standard, whereas with an emission tax the invention may allow the firm to reduce both costs and, by reducing its emissions, its tax payments.

The impact of any of these instruments on innovation will also depend on how the policies are revised after an innovation has occurred, and on what the affected firm expects this revision to be. Since such revisions could increase costs to some firms to a level higher than what prevailed without innovation, it appears that any instrument may actually inhibit innovation.

Barry Commoner [1971] has argued that innovations have had a bias which has harmed the environment, listing in defense of this proposition numerous new processes and products which are more harmful to the environment than those they replace. He argues that the environment can be considered a factor of production with a zero price, and finds evidence that over time pollution per dollar of GNP has increased. The latter argument has an interesting defect: we cannot tell whether substitution between the environment and more expensive factors of production or technological change is responsible for increasing pollution. The reason, of course, is that changing relative prices may be accompanied by both substitution and technical change. In general, to disentangle the effects one needs some independent estimates of the magnitude of one of the effects.

A step toward careful examination of this problem has been made by Adam Gifford [1973]. He assumes the existence of a trade-off between environment-saving and factor-saving innovation, and examines the effect of an emission tax on technology. He also finds conditions under which pollution can be reduced without any reduction in the production of commodities.

In an unpublished paper, V. Kerry Smith has made similar use of the assumption that there is a fixed trade-off between innovations which save on standard factors, capital and labor, and innovations which tend to reduce impact on the environment. He shows that, under very restrictive assumptions of a Cobb-Douglas production function and a linear innovation possibility frontier, innovations which reduce damage to the environment vanish if the price of environmental services is zero.

There has been a useful study (Jacoby and Steinbruner [1973a]) of the development of new technology to meet emission standards for new vehicles. This study and a study done for the Office of Science and Technology conjecture that the very specific combination of performance criteria and time horizon in the Clean Air Act made the choice of adding additional equipment to the existing internal combustion engine the clear optimal choice for the industry. Bain [1970] has also commented on this choice. Unfortunately, although attractive, this conjecture has never been supported by further work.

Obviously, any improvement in our understanding of the innovative process in general will contribute to our understanding of the effect of environmental policy on innovation. Theoretical research into the response of innovation to price changes could improve on the rather ad hoc models applied by Gifford and Smith to the analysis of the effect of effluent charges on innovation. Indeed, any of the theoretical

work recommended elsewhere in this project would contribute to the analysis of this policy area.

The effluent charge is only one, and a rather minor one, of the policy instruments used to regulate environmental impact. Performance standards and equipment standards are more commonly used, and have obvious impacts on the innovative process. Comparisons of such instruments based on detailed empirical work are needed.

The impact of specific policy instruments may vary with the organization of the industries to which they are applied. The findings of Kamien and Schwartz and others on the relation between market structure and innovation are relevant to this endeavor, but nowhere have such models been applied to the explanation of the effect of environmental policy on innovation. In particular, a study along these lines of the automobile industry is desperately necessary.

Finally, there is an obvious relation between the expectations held by regulated firms as to how the environmental controls will be enforced and the way innovation responds. There is, for example, a considerable folklore that the automobile industry has lagged in innovation because of its belief that standards will not be enforced if it fails to produce an engine which can meet the standards. Although Jacoby and Steinbruner [1973a and 1973b], Bain [1970], and Klein [1974] provide some comments on this problem, there has been no detailed study which is adequate to establish whether or not the automobile industry has lagged, and if it has, why. Looking at the regulatory process as involving mutual interaction between regulators and regulated is a necessary first step to model adequately the relation between any kind of regulatory action and innovation (see Noll [1971]).

TRANSPORTATION

Studies of the transportation sector are so numerous that "transportation studies" has almost become a discipline onto itself. Economists have studied virtually every aspect of the efficiency of transportation, including the effects of various government policies, and the engineering literature contains numerous studies of potential developments in transportation technology. Unfortunately, neither literature appears aware of the existence or the frame of reference of the other. Only in a few instances have studies immediately come to grips with the relationship between policy and innovation in the transportation sector, and in nearly every case the resulting publication has been a discursive, journalistic allegation of a particular effect, rather than a completely convincing scientific inquiry.

The folklore of transportation economics is that regulation has undermined efficiency in the transportation sector on almost every front. Scholars who have studied surface freight transportation have concluded that regulation imposes annual costs of several billion dollars by causing irrational allocations of freight by mode and by requiring uneconomic services and empty back-hauls (see Friedlaender; Meyer, Stenason, Peck and Zwick; and Moore). In all of these studies, thwarting cost-saving innovations contributes to the cost estimates, at least implicitly; however in none is there systemmatic investigation on a theoretical level of the mechanism by which this happens, the behavioral system that causes these effects, or even their approximate magnitudes. Similarly, comprehensive studies of air transportation usually make references to technical choices, but do not systemmatically study them (see Caves, Eads). Finally, studies of the effect of regulation on prices are purely static, rarely even making reference to technological innovation (see Farmer, Keeler, Levine).

Case Studies

When the effects of regulation are examined, the method employed is normally a discussion of a particular innovation that was (unwisely) promoted or retarded by regulators, not always intentionally. The best literature on the effects of regulation on the innovative behavior of industry is the series of case studies to be found about transportation innovations; however, for reasons to be elaborated below, the best is still not very illuminating.

Fairly convincing evidence has been assembled to show that three railroad innovations were seriously retarded by the policies of the Interstate Commerce Commission. In a study of the ICC's response to the unit train, MacAvoy and Sloss show that the innovation was economically warranted and desired by the industry about forty years before it was widely adopted. But adoption was delayed because the ICC demanded that new services be offered to all customers at comparable costs, whereas it made no attempt to undo price discrimination in existing services. As a result, the profits to be gained by the railroads from capturing business from other modes (notably water transport) by offering unit train service were more than offset by the reductions in profits they would have experienced by offering the service to existing customers who had no opportunity to use other modes and who, therefore, were being charged very high prices for the old service.

Although less convincing than the MacAvoy-Sloss analysis because of the absence of actual cost and revenue data, it still seems clear on the basis of published research that the ICC did severly retard two other innovations: the Big John hopper car and piggyback truck-rail shipping. The Big John case (see Gellman [1971]) involved the introduction of a new, large car for hauling grain that enabled the user of the car, the Southern Railway, to reduce rates

about sixty percent if shippers' agreed to use the entire car and to ship directly from origin to destination, waiving transit privileges. Other grain shippers, notably the barge lines who really had no effective competitive response, bitterly fought the Big John system, and twice the ICC vacated the new rates. Eventually, under pressure from adverse court rulings, the ICC permitted the new rates and thereby made possible the adoption of Big John cars; however they had succeeded in delaying full use of the innovation for more than four years.

The piggyback case (see Gellman [1971] and Note) involved a similar type of conflict among freight modes, and a similar result in terms of retarding a cost-saving innovation. For various reasons having to do with the technical problems of attaching trucks to railroad cars, handling flat cars in switchyards, and accommodating car design to the realities of the roadbed, the cheapest technology for piggybacking was to use a very short flatcar, large enough for but one truck, and to transport only the freight container of the truck instead of the entire trailer. But the ICC policy of establishing rates on the basis of historical average costs prevented the rails from adopting the best technology, since they could not set a low enough price to encourage use of piggybacking if they carried only one truck per car nor could they incorporate into the price structure an incentive for truckers to use trucks with detachable freight containers. Consequently, piggybacking is more expensive and less fully utilized than it could be. Unlike the Big John case, there is no indication that the ICC actively used average-cost pricing to retard the innovation and thereby reduce the incursion of railroads into the long-distance shipping business of truck firms. Nevertheless, the ultimate consequence was similar: to blunt the extent to which an innovation was permitted to produce intermodal redistributions of wealth.

Less well-documented "horror stories" about the impact of regulation on transportation innovation are part of the folklore of those who are interested in transportation policy. Gellman's studies of aircraft and surface transportation contain several examples, the ICC practice of awarding trucking licenses for particular commodities between particular routes discourages the development of more general purpose, flexible trailer design; incomplete cost accounting for determining rates discourages the development of lighter, road-saving trucks; in similar fashion, the fact that during one historical period airlines actually showed accounting profits from crashes due to liability limits, depreciation rules and insurance procedures probably limited incentives for safety innovations (see also Phillips [1971a]). Existing rules for interfirm rental of freight cars have probably reduced the incentive for cost-reducing innovations here (see Capron and Noll). Entertaining journalistic "exposes" of ICC reactions to rail innovations are also periodically undertaken by John Kneiling in his column in Trains, a magazine for railroad buffs, which is a good place to look for ideas for research topics on technological change in railroads.

Regulators do not always act to retard innovation; just as often they make decisions that provide unjustifiably strong economic signals to adopt new methods. In some cases the attempt to maintain high rates for low-cost services induces the development of new industries: pipelines were developed to some extent in response to very high prices for shipping fuels by the surface modes regulated by the ICC (see Gellman [1971]), and the development of very small commuter planes has been promoted by the subsidies provided to general aviation in the use of FAA facilities (see Warford) and the minimum weight limit that defines which passenger airlines will be regulated (see Eads). Much has also been written about the incentives generated by CAB regulation for airlines to engage in service

competition since price competition is foreclosed, producing adoption of larger, faster planes (notably short-haul jets) more rapidly than is economically justified (see Eads and Gellman [1968]); however Phillips argues that technical developments in aircraft are largely due to exogenous scientific breakthroughs [1971b] and that, because the CAB normally reflects the interests of the airlines, the mistakes arising from regulatory rules are really the mistakes of the airlines [1971a]).

Finally, the transportation sector, particularly aircraft construction, has had much of its technological development paid for by the government, some indirectly as spin-offs from military development, some through FAA subsidies of air traffice control and safety, and some through direct research programs of NASA and more recently federal support of research on urban mass transit and alternatives to the internal combusion engine. Although the relationship between military and civilian research and innovation in aircraft has been rather thoroughly studied (see Phillips [1971b] and his references), none of the others have received any systemmatic scrutiny. And even the Phillips study pays scant attention to the relationships between the rate of diffusion from military to civilian use of new technology and the regulatory environment of the carriers.

Generalizations on Policy and Innovation

The few specific case studies described above usually also include more general statements of the relation between policy and innovative performance, usually stated as loosely-derived hypotheses, but sometimes based upon formal manipulations of relatively complete microtheoretic models. In addition, a few papers have been written about the interactions between policy and innovation that clearly apply to transportation, but deal with a broader segment of the economy. The following is a summary of the hypotheses that has been offered:

(1) Valuing investments at replacement costs encourages firms to keep old capital longer, thereby prolonging the introduction of capital-embodied innovations (Johnson)

(2) Price regulation of competitive industries creates an excessive incentive for service-improving innovations (Caves, Gellman [1968], Eads, Douglas and Miller).

(3) At the same time, price regulation reduces the incentive for cost-saving innovations by limiting their potential market penetration (see Gellman [1971], Klein); however, this depends on implicit assumptions about the appropriability of innovations -- the ability to capture the markets of others depends upon the ability of others' to copy your innovation; also, the absence of price reductions due to regulation could, when demand is inelastic and regulation prevents competition, increase incentives to innovate).

(4) Because regulation eliminates business risk and severly restricts the freedom of firms to change operating methods, it encourages a corporate laxity that is inconsistent with innovative behavior (see Klein, Leibenstein); however, reducing the risk of innovation can promote it as well (see Capron).

(5) Because the regulatory process is characterized by long delays in reaching decisions (i.e., regulatory lag), innovations that require active administrative response for approval will be

thwarted while those which can be adopted without approval and which an agency must respond to in order to reestablish the old profit rate and wealth distribution will be encouraged (see Capron, Joskow).

(6) Regulation creates an incentive for new industries that can avoid regulation (see Johnson on pipelines and Eads on commuter airlines).

(7) Rate-base regulation encourages capital-using innovations for the same reasons that, in a static model, it encourages excessive capital-intensivity (see Averch and Johnson, Westfield).

(8) Because of the way in which information is introduced and used in regulatory proceedings, the beneficiaries of technological change are likely to be accorded less weight in decisions than are those who stand to lose by it, making regulators more risk-averse than are market participants (see Noll).

(9) Cartel-like industry organizations, such as the ICC, inevitably reduce the number of innovations; because they operate by majority-rule, innovation proceeds according to the vision and innovative propensity of the member of the cartel at the median position, whereas in a competitive situation only one firm need be convinced, rightly or wrongly, of the value of an innovation in order for it to have a market test (see Davis).

Conclusions and Recommendations

Certainly the overriding impression to be derived from reading the literature on transportation is that the government has pretty

throughly mucked up the rate and direction of technical progress. Generally, the conclusion is that American society has had too much innovation with respect to air transportation, technologies using the highways and, perhaps, pipelines, and too little innovation with respect to rails. In addition, within each component of the industry innovation has been biased by policy instruments: too much emphasis on speed, too little on cost-economizing, particularly with respect to spill-over effects, highway deterioration and the full exploitation of each mode's inherent advantages.

The literature is far less suggestive of what could be done about the situation, other than abandoning regulation, giving regulators explicit instructions to change their ways, or subsidizing activities to overcome institutionalized uneconomic incentives. The limited range of policy options arises because researchers rarely let the regulatory process become a part of their conceptual model. The otherwise excellent studies of the performance of various parts of the industry mentioned above, and even the best studies of particular cases when innovations were unwisely retarded or promoted, contain no more than brief references to the process by which policy produced an unsatisfactory result.

In order to produce adequately documented arguments for policy changes towards the transportation sector, two kinds of research are necessary. First, case studies like that of MacAvoy and Sloss, where the economics and engineering of a new innovation are throughly examined and net benefits estimated, are absolutely essential. Second, more emphasis in all research must be placed on the factors that govern the establishment and maintenance of regulatory policies. A particularly fruitful line of inquiry would be to blend these suggestions into comparative studies of innovations, some of which were adopted by firms without any apparent attempt by regulators to interfere with the

process, in order to sort out the characteristics of a proposed change that are most likely to generate unwise intervention by regulators. The ICC is a particularly good candidate for such research, where numerous freight car innovations are available to provide an adequate sample for examining the behavior of the agency, the railroad industry and other modes under differing situations.

Various government attempts at direct subsidization of transportation should also be examined. Thus far, no systemmatic study has been attempted of why the VTOL and STOL research programs have not led to commercially exploitable innovations in aircraft. Was the cause the difficulty of fitting such craft into a regulated air fleet? Or was it the difficulty in obtaining urban landing sights that could take full advantage of the technology? Or was the whole concept a bad idea -- and if so, why has so much been spent on developing it for so long? Is there anything about this program that would shed light on the ability of the government to select and execute valid developmental projects in the area of transportation technology? Similar questions can also be asked about the "people-mover" projects, the research into high-speed rails, and attempts to develop alternative automotive propulsion systems.

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